# ATTACHMENT B

## Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

**Submission Title:** [C-band satellite interference measurements at TDK RF test range]
**Date Submitted:** [12 January, 2004]
**Source:** [Presenter 1: Evan Green] Company [Intel]
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**Abstract:** [This document describes UWB interference testing to C-band satellite TV receivers]

**Purpose:** [For peer review and discussion regarding interference and regulatory issues]

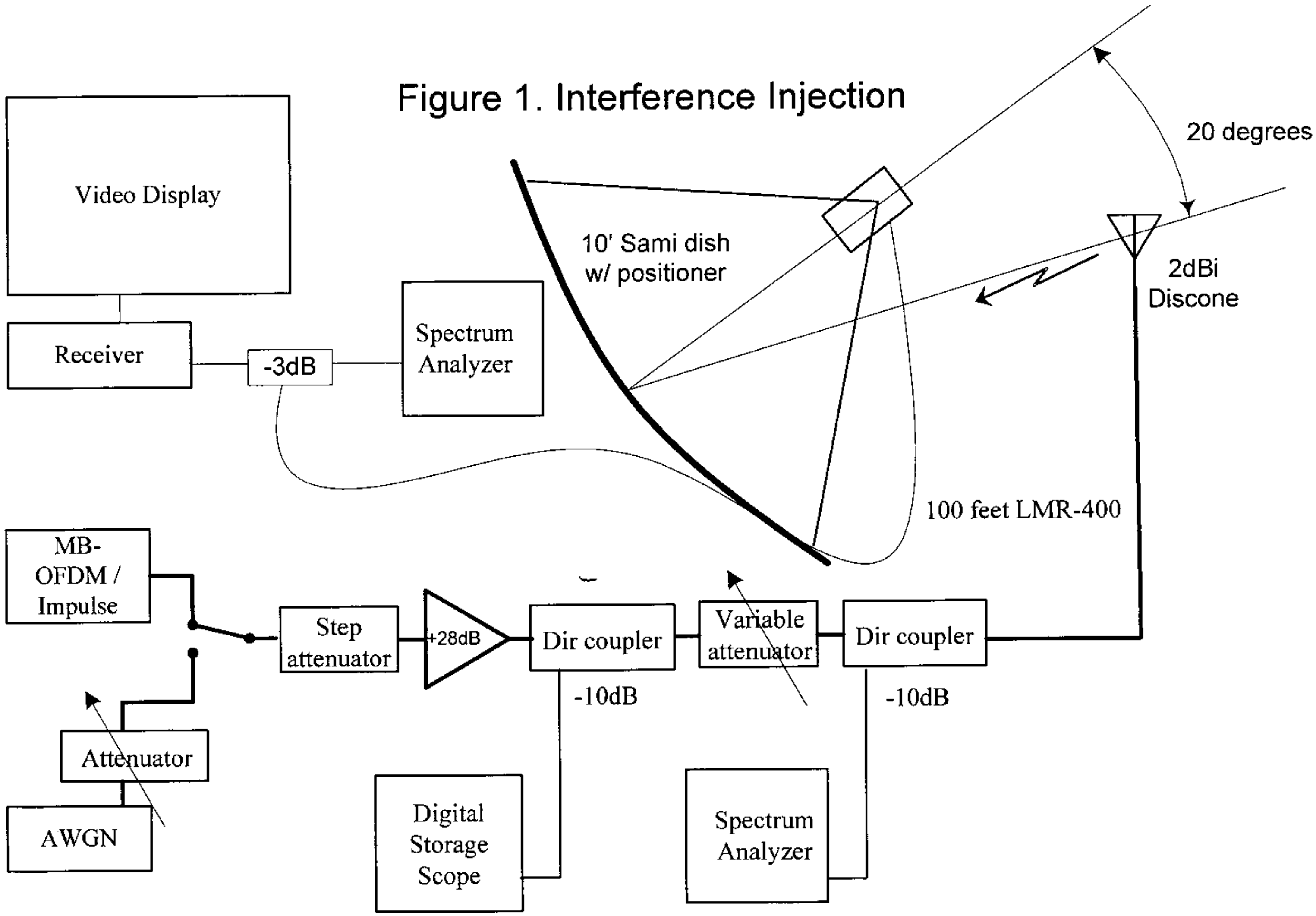
# Test Objectives and Facility

- Objectives:
  - Measure interference potential to C-band TV service
    - FSS C-band 3.7-4.2GHz
  - Compare WGN, MB-OFDM & Impulse UWB signals
  - Investigate relative interference threshold
  - Determine safe distance from dish antenna to avoid interference
- Test facility
  - Measurements conducted at outdoor RF test range
    - TDK RF test facility in Austin, TX
    - Tests conducted Dec 8-18, 2003
  - Satellite TV reception system installed by Austin area provider
  - Dish size selected by provider as typical for the area

# Test setup

- Figure 1 on next page depicts the equipment configuration
- Satellite TV reception system
  - C-band system with auto positioning dish
  - 10 foot Sami dish selected by provider as typical for Austin area
  - Motorola DSR-922 receiver selected due to popularity
- UWB test transmitters
  - MB-OFDM 528MHz bandwidth, 3 band mode w/ zero CP
  - 3MHz PRF impulse mode
  - WGN generator used to emulate a DSSS system
- RF distribution circuits provide
  - High isolation coaxial switch used for quick A/B comparison
  - Amplifier compensates for loss in 100' coax feed line
  - Calibrated attenuators used to set power levels accurately
  - Directional couplers used for signal observation only

Figure 1. Interference Injection

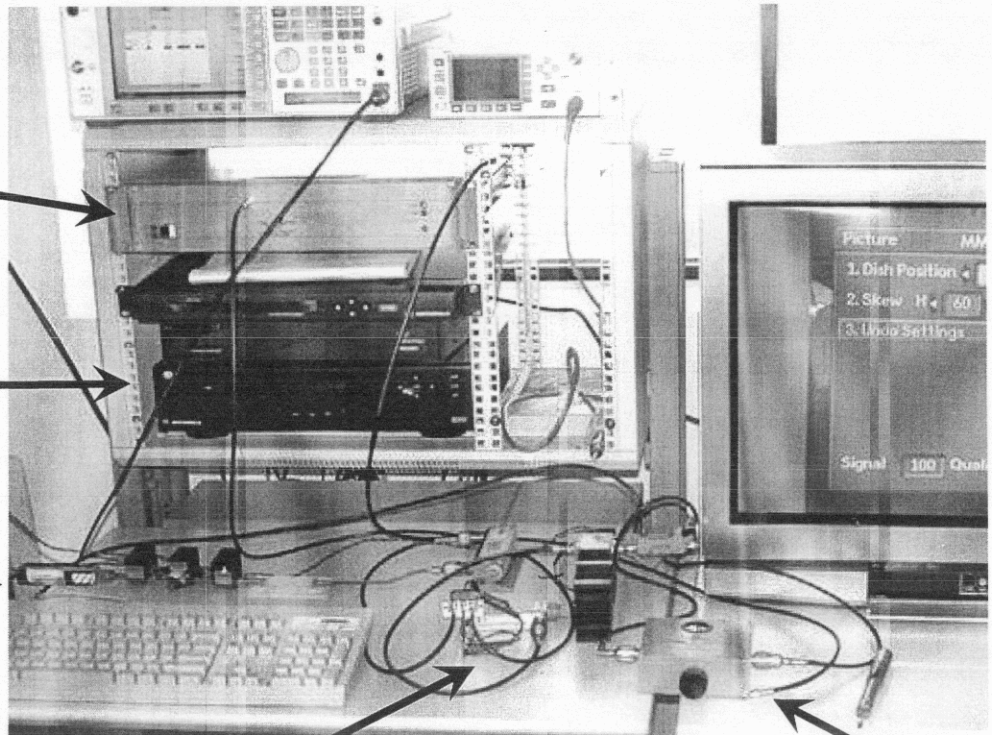


# Test equipment setup

Wisair UWB TX

C-band receiver

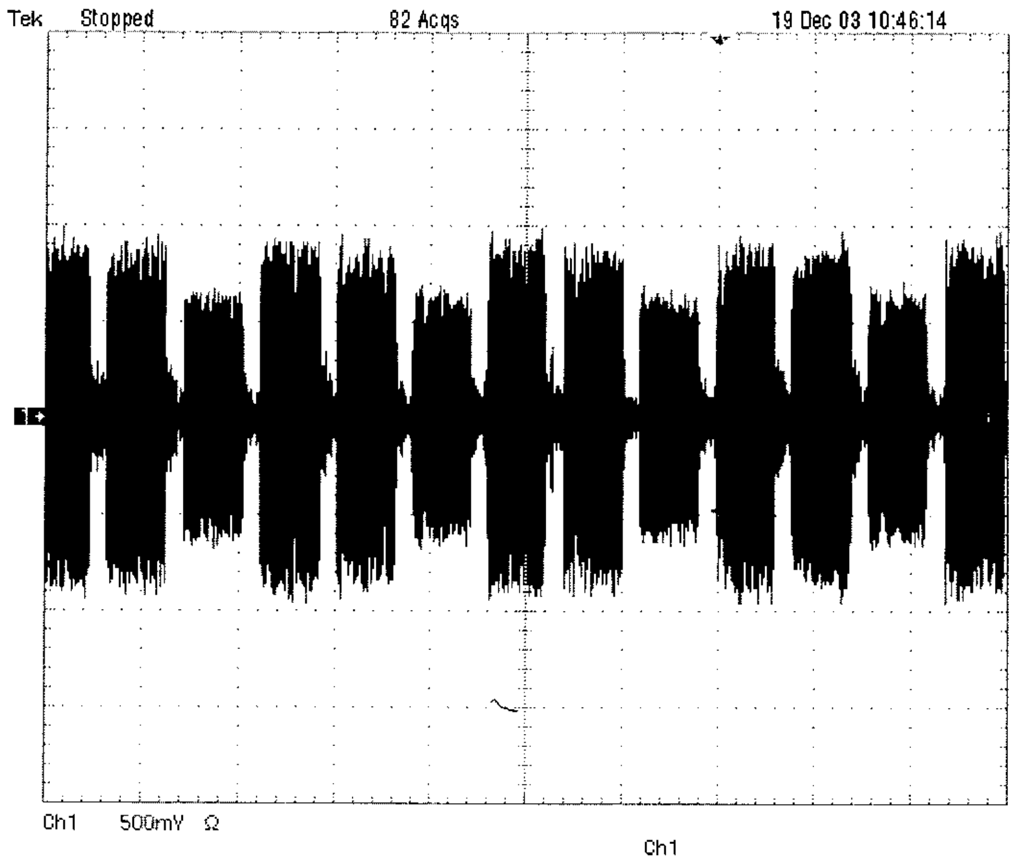
AWGN source




RF switch & distribution

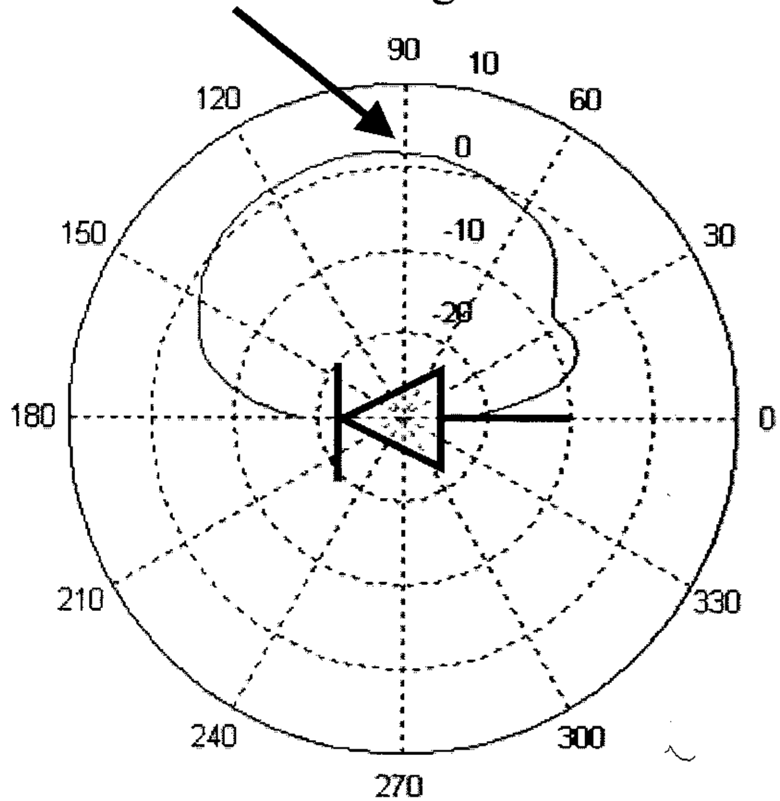
Variable attenuator

# MB-OFDM Waveform F1F2F3

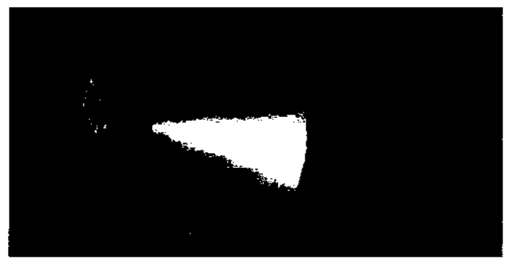


# Discone UWB antenna gain

2dBi broadside antenna gain




Broadside orientation used in tests



# Test System Calibration

- Attenuators enable power changes accurate to less than 0.1dB
  - Step attenuators calibrated to NIST traceable standard
  - Variable attenuator checked with thermal power meter (traceable)
- UWB field strength
  - Set to FCC level using EIRP method
  - Measured with spectrum analyzer per FCC rules
    - 1MHz RBW, RMS detector, Peak hold
  - TX power measured at antenna connection
    - Compensates for loss in 100' transmission line
    - Power set to -43.3dBm/MHz within satellite receiver bandwidth
    - 2dBi antenna gain brings EIRP to -41.3dBm/MHz (FCC)
  - All UWB generators set to the same power level
    - No backoff for frequency duty cycle

# Receiver Operating Point

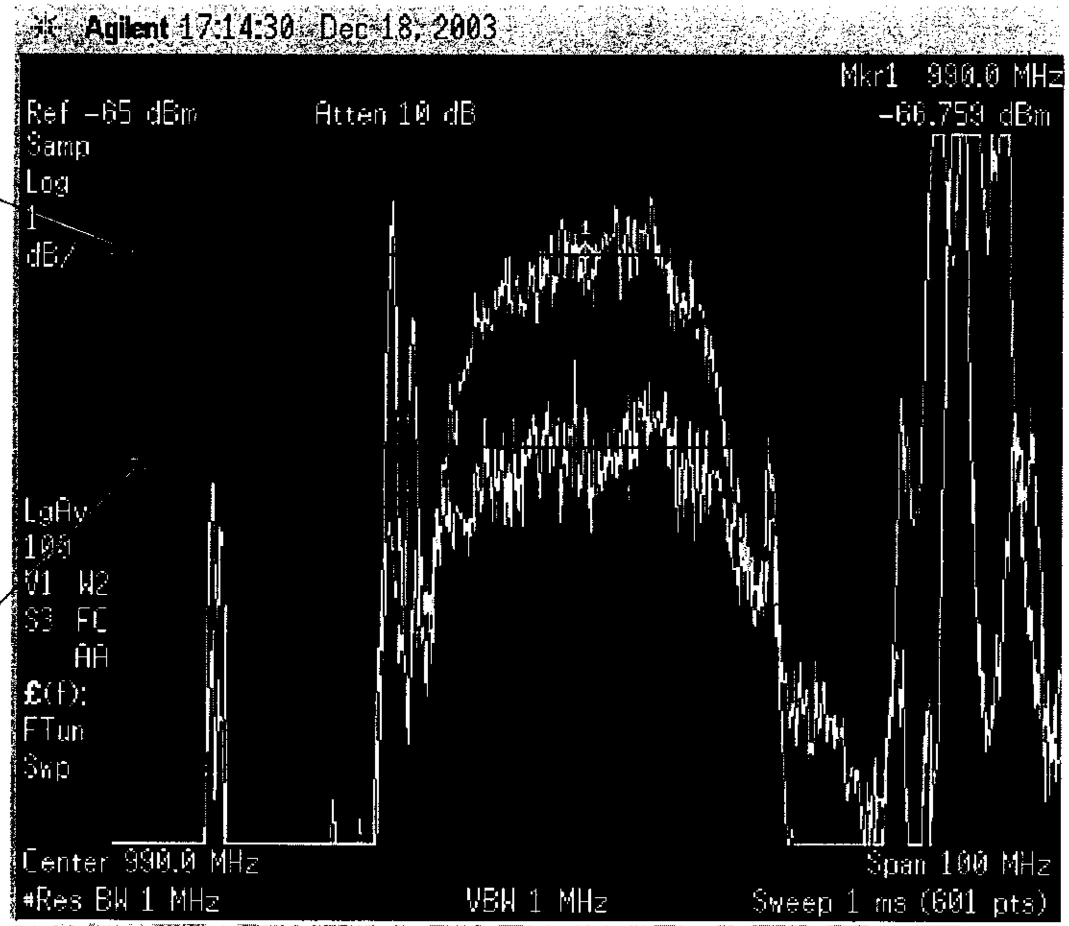
- Several methods attempted, final method described here
- Dish azimuth and elevation adjusted for maximum signal power
  - Adjustment improved signal by 0.5dB above automatic positioner
- Elevation increased to reduce signal power
  - Pointing away from satellites
- Signal power set to minimum for error free video
  - This is receiver minimum sensitivity point
  - Signal power fell by 2.5dB (operating margin)
- Elevation was adjusted to set receiver operating points
  - 2.5dB, 1.0dB & 0.5dB above sensitivity

# Receiver operating point

Maximum signal power

Receiver input signal
Fc = 990MHz = 5150 - 4160
5150MHz (LO)
4160MHz (C-band signal)

Signal power at minimum sensitivity



# Relative Interference Measurement

- Satellite Galaxy 1R (G1)
  - Channel MMAXW, fc=4.16GHz
  - Digicipher II stream (QPSK, 7/8 FEC, 29.27Ms/s)
- UWB antenna placed within 20° elevation of dish boresight
- RF power of AWGN and MB-OFDM calibrated (each time)
- RF switch set to AWGN signal and attenuators set to the threshold of visible artifacts in the video
- RF switch set to MB-OFDM and signal power reduced to find the threshold of visible artifacts in the video
- Above procedure repeated for AWGN vs. Impulse UWB
- Record power changes by reading variable attenuator only
  - Most accurate method for relative power indication

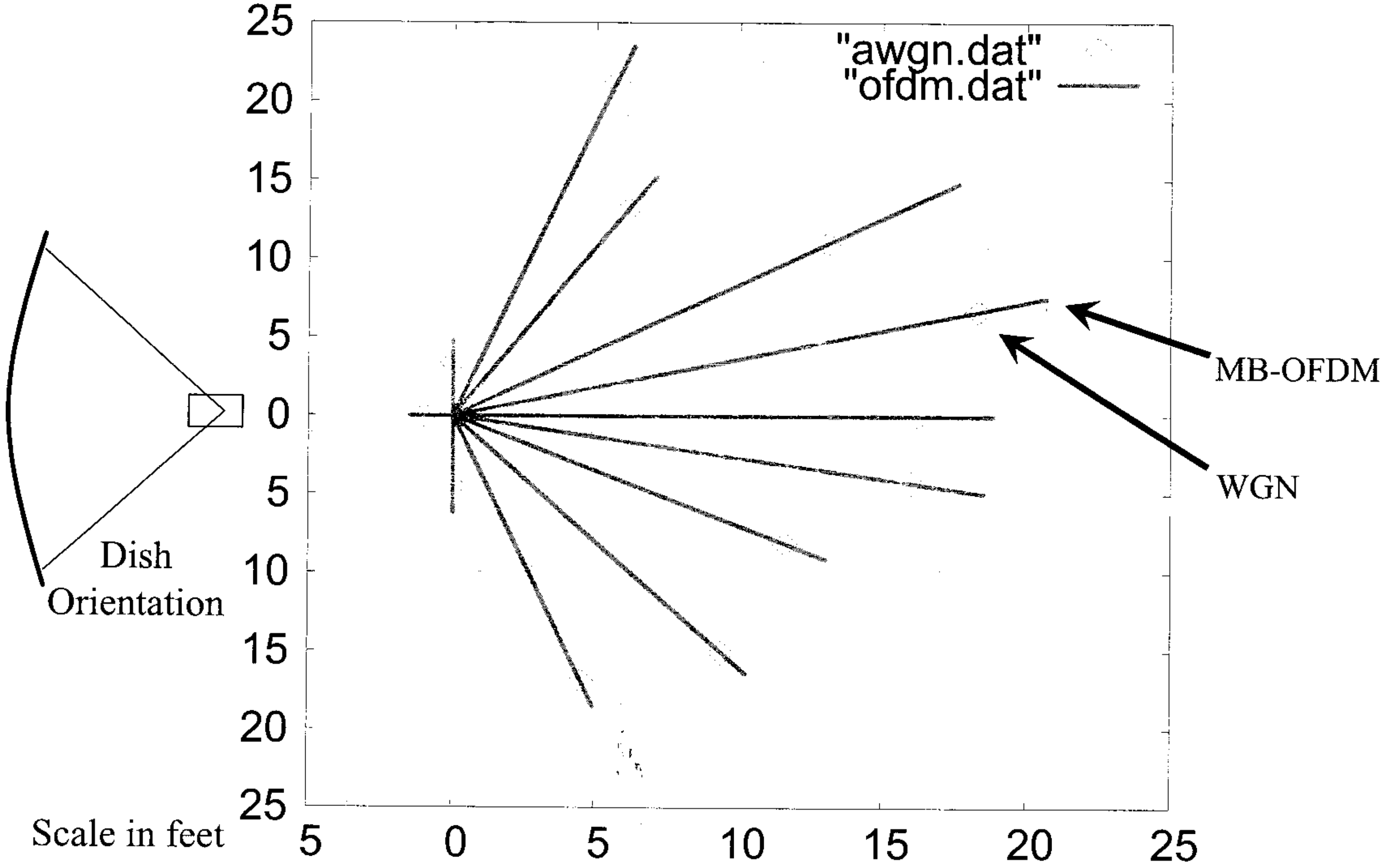
# Interference threshold Measurements dB relative to AWGN

| Emission | 0.5dB Above Sensitivity | 1dB Above Sensitivity | 2.5dB Above Sensitivity |
|---|---|---|---|
| AWGN (DSSS) | 0.0dB | 0.0dB | 0.0dB |
| MB-OFDM F1F2F3 | -1.1dB | -1.2dB | -1.6dB |
| Impulse 3MHz PRF | -1.9dB | -3.8dB | -4.0dB |

# Safe Distance Measurements

- Satellite selected Galaxy 1R (G1)
  - Channel MMAXW, fc=4.16GHz
  - Digicipher II stream (QPSK, 7/8 FEC, 29.27Ms/s)
- UWB antenna placed within 20° elevation of dish boresight at furthest distance
- RF power of AWGN and MB-OFDM calibrated per procedure above (each test)
- RF switch set to AWGN signal and antenna moved closer to the dish to find the interference threshold; mark with red flag
- RF switch set to MB-OFDM and antenna moved away to find the threshold of artifacts; mark with green flag
- Above repeated at different azimuth angles relative to the dish
- Above repeated for AWGN vs. Impulse UWB using blue flags

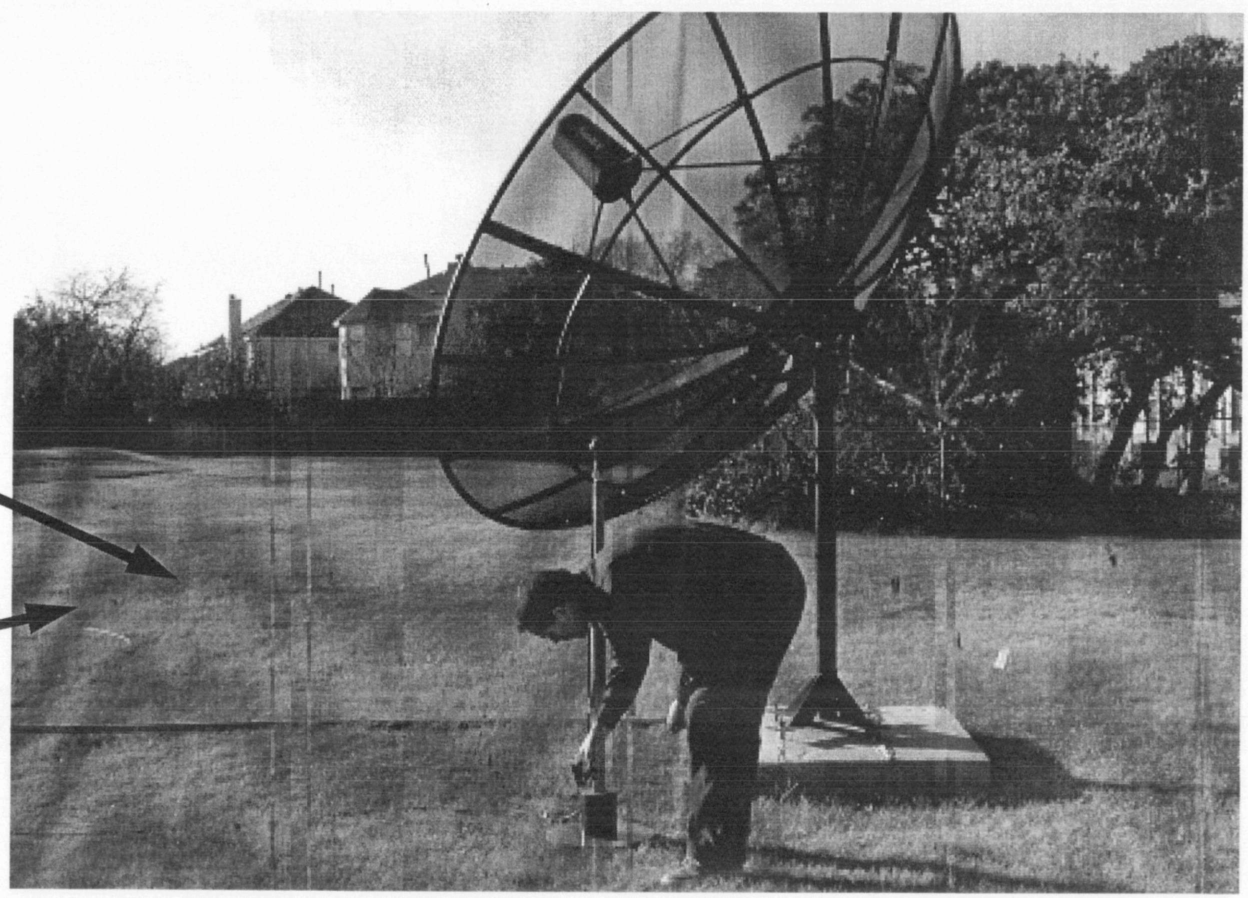
# Safe Distance Measurements



# Safe Distance Measurements

Red flags mark WGN

Green flags mark MB-OFDM



# ATTACHMENT C

# Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

**Submission Title:** [APD plots and their implications for MB-OFDM UWB interference]
**Date Submitted:** [9 July, 2004]
**Source:** [Charles Razzell] Company [Philips]
Address [1109, McKay Drive, San Jose, CA 95131, USA]
Voice:[+1 408 474 7243], FAX: [+1 408 474 5343], E-Mail:[charles.razzell@philips.com]
**Re:** [An often cited reason for no-votes in 802.15.3a down-selection process ]

**Abstract:** [Presents simulated APD plots for MB-OFDM and discusses implications for interference]

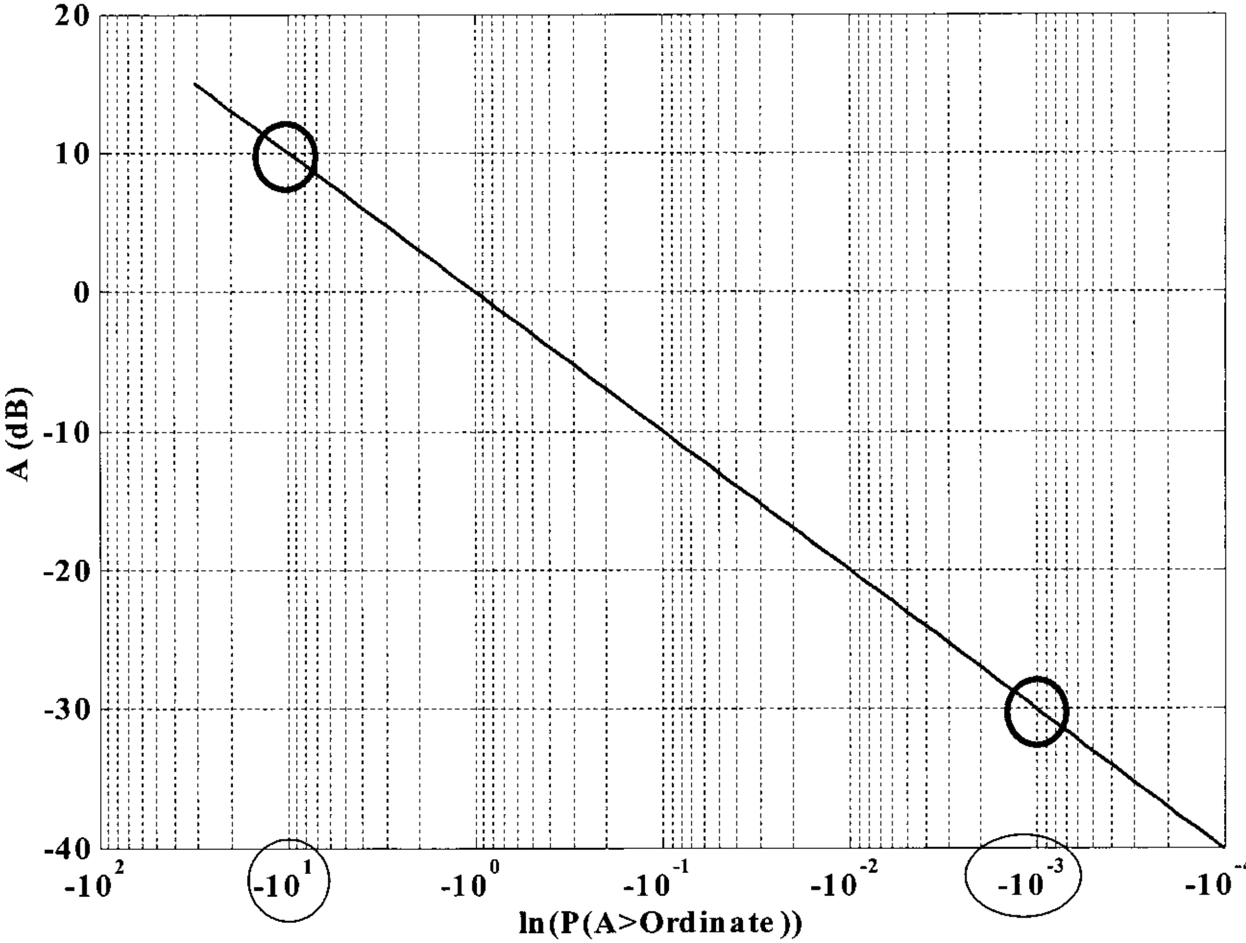
**Purpose:** [Consider how MB-OFDM compares to other UWB waveforms anticipated by FCC rules.]

# APD Plots and their Implications for MB-OFDM

# Amplitude Probability Distributions

- APD methodology is favored by the NTIA in assessing interference impact of UWB waveforms
- For non-Gaussian interference, APD plots provide helpful insight into potential impact on victim receivers.
- For full impact assessment, knowledge of the victim system's modulation scheme and FEC performance is needed

# Example APD plot (for Guassian Noise)



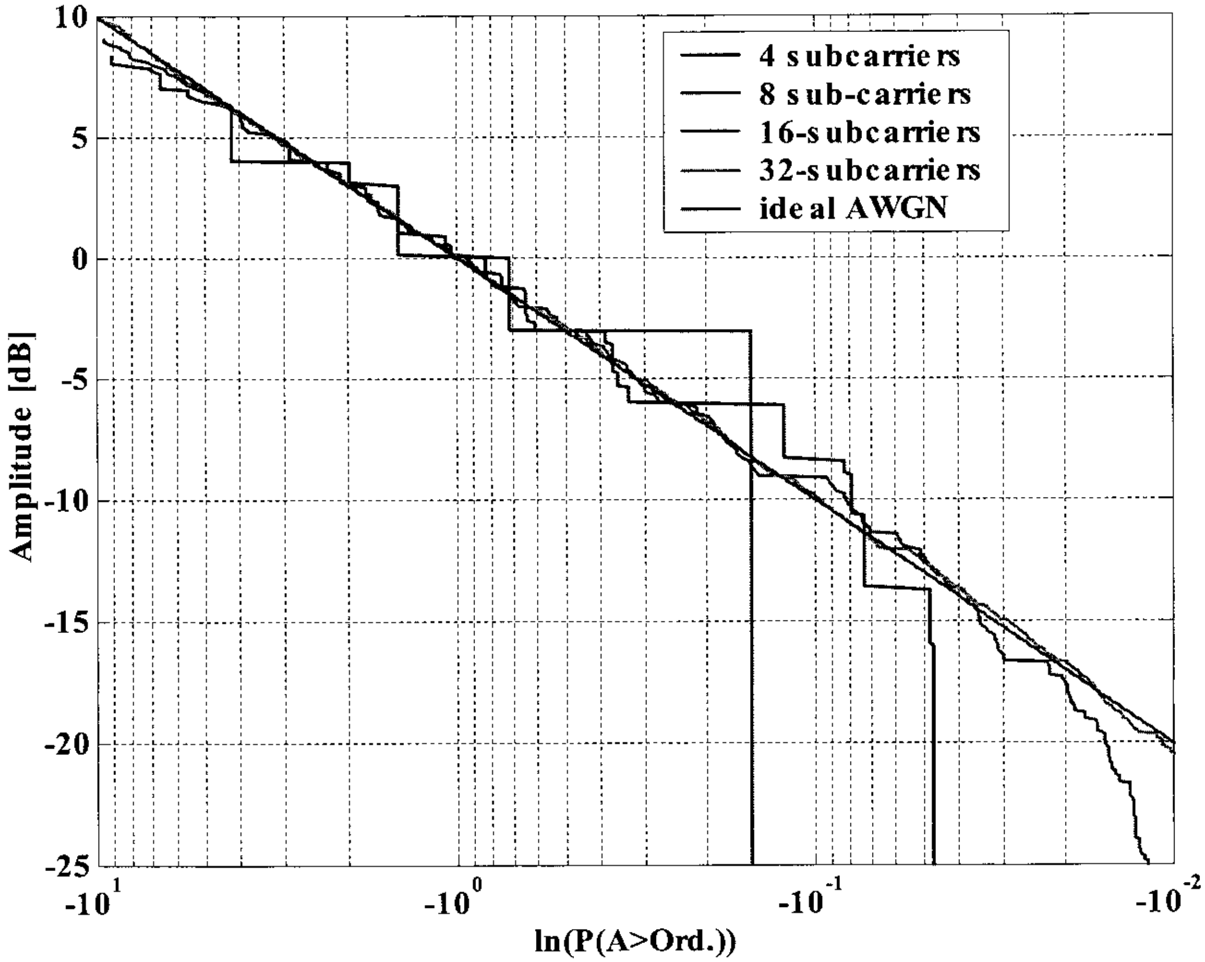

Amplitude (A) in dB is plotted as the Ordinate

1-CDF(A) is plotted as the Abscissa

Plotting the natural log of the probabilities on a log scale provides scaling similar to Rayleigh graph paper.

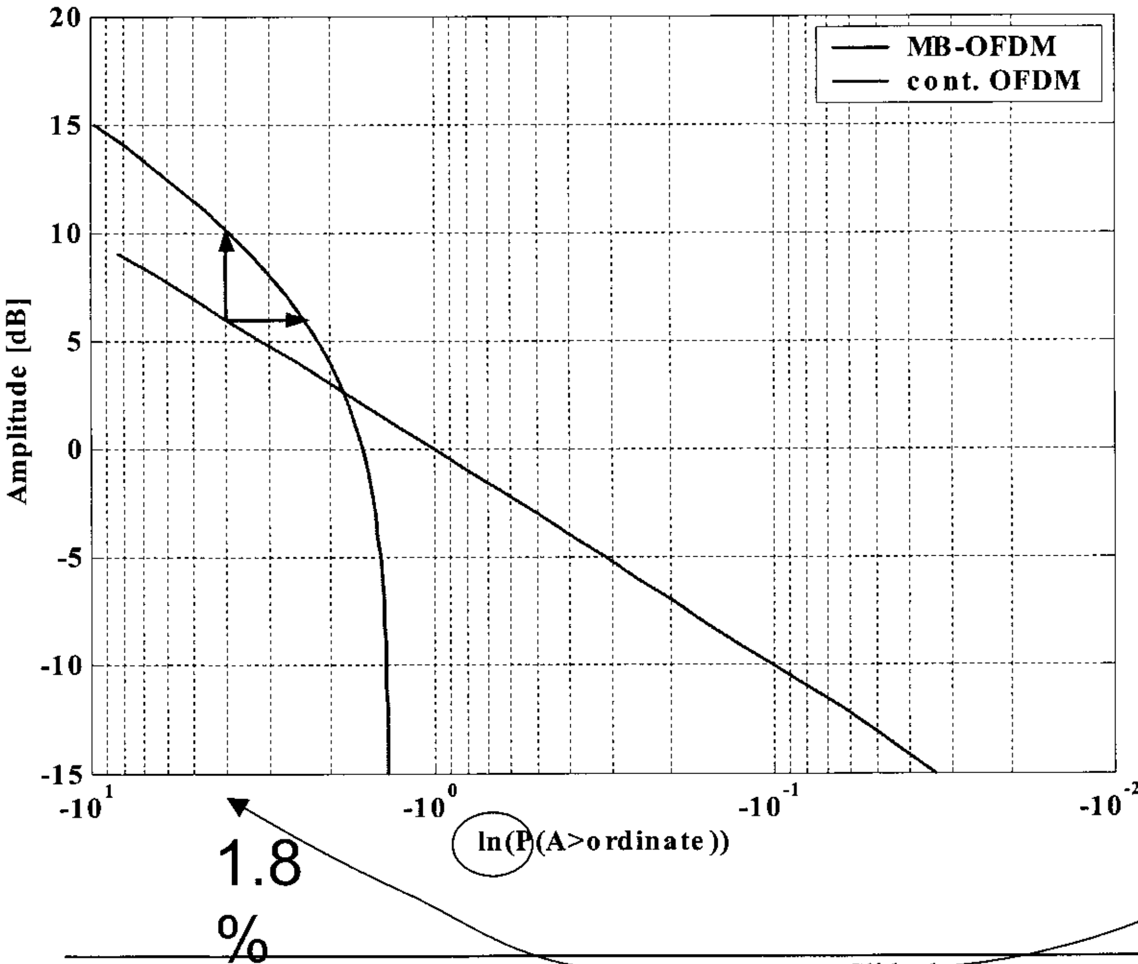
P(A>10dB) = exp(-10) = $4.54 \times 10^{-5}$ ;  P(A>-30dB) = exp(-0.001) = 0.999

# APD plots for continuous OFDM signals as bandwidth is varied.




As the number of sub-carriers used increases, the approximation to the AWGN APD plot improves. This can be expected due to the Central Limit Theorem.

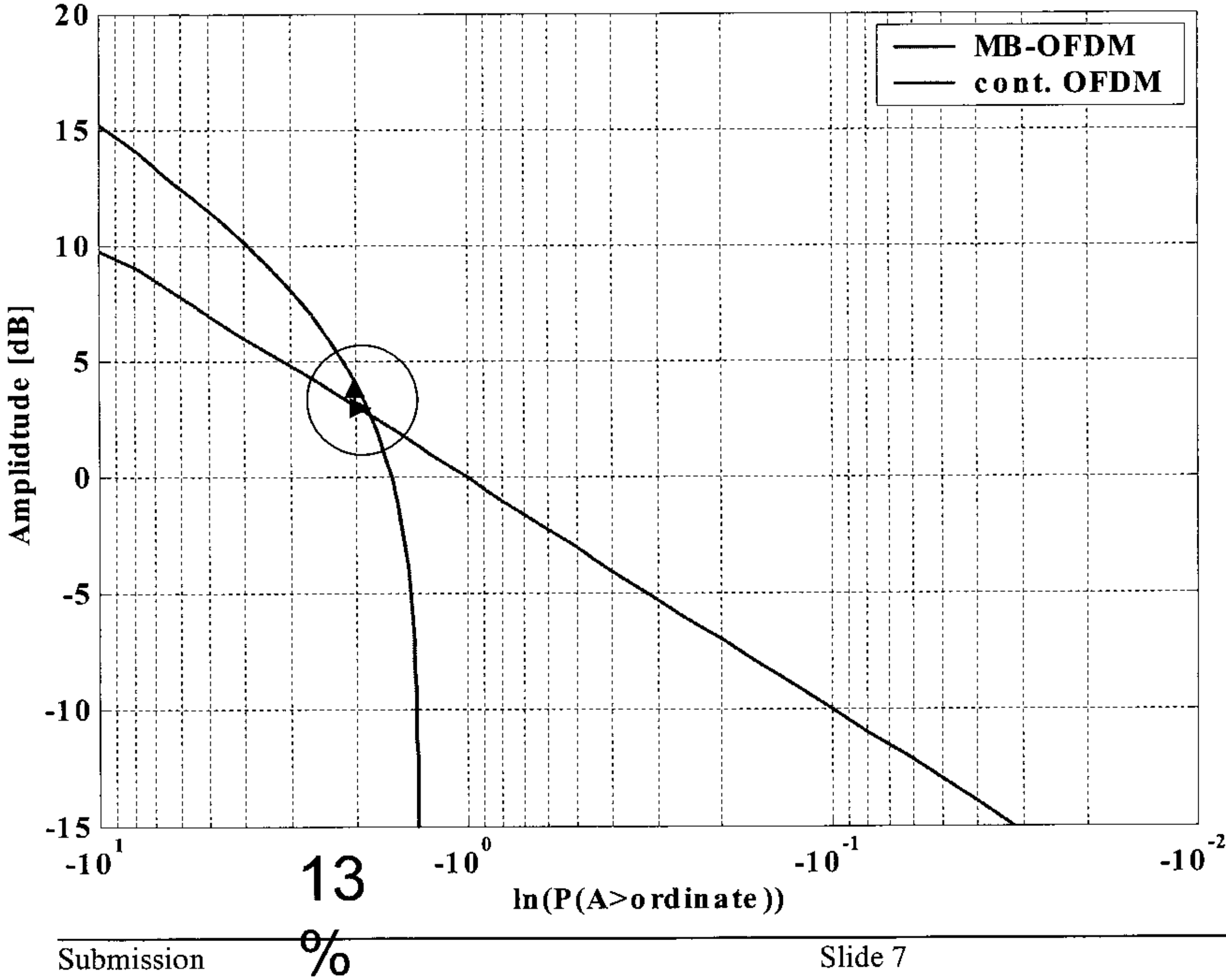
# Simulated APD plots for continuous and 3-band OFDM, using 128 sub-carriers




Signal/interferer is normalized to unit power 0dBW.

Probability of noise amplitude exceeding signal amplitude is given by abscissa value at the intersection of a horizontal SIR line with the APD curve.

# Simulated APD plots for continuous and 3-band OFDM, using 128 sub-carriers




Comparing the same two systems at 13% probability brings them closer together.

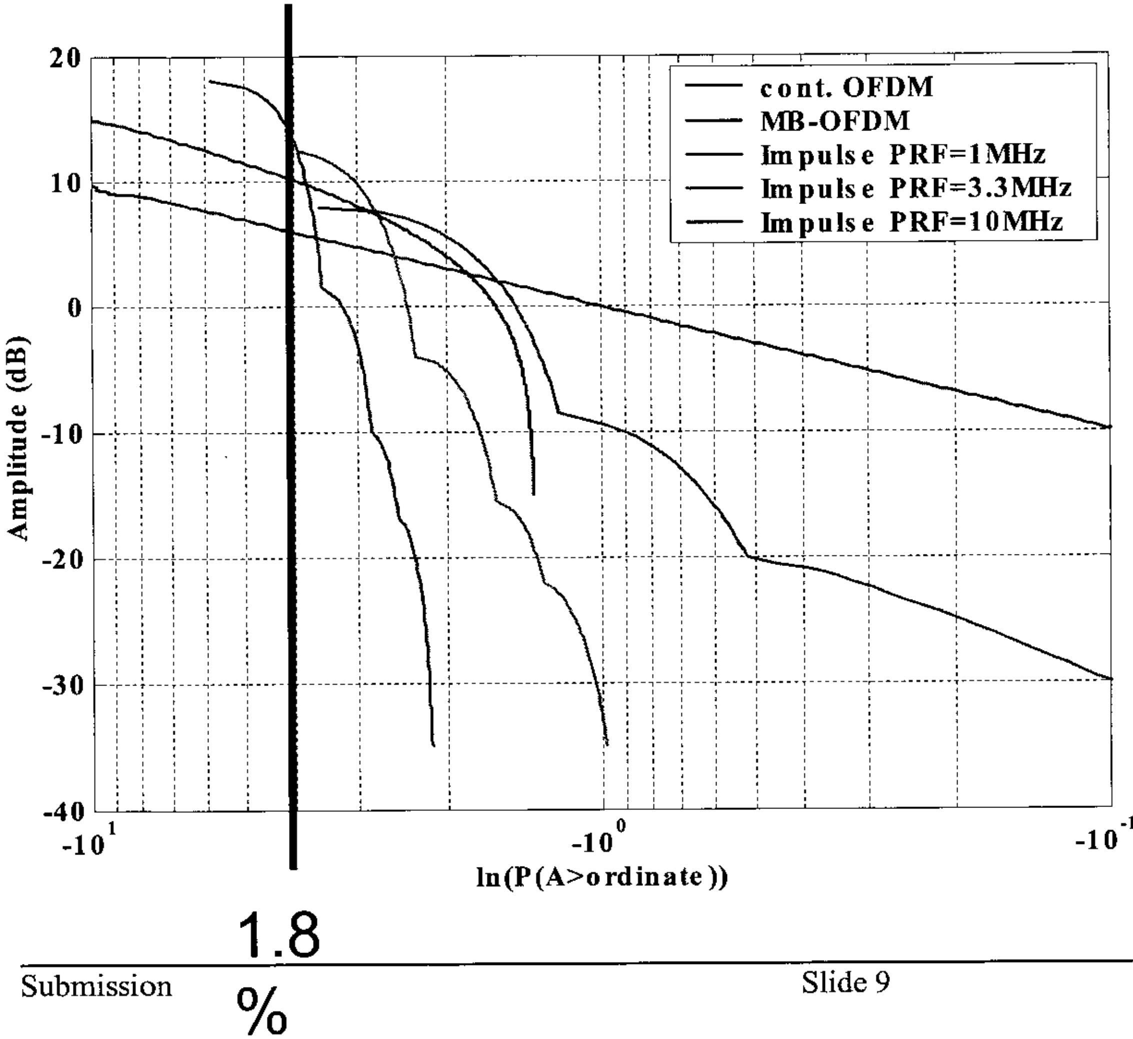
An indicative approximation of uncoded BER is sometimes taken as ~½P(A>ord.).

(Depends on modulation scheme)

# Suggested Probability for comparing systems

- Suggest P(A>ord.)=1.8%
- Corresponding pseudo uncoded "BER" is 0.9%
- Any reasonable FEC should perform well under this number of input errors
- Region to the left of P(A>ord.)=1.8% may not be significant for digital victim receivers
- For AWGN this "error rate" occurs with SNR=6dB, which seems a reasonable operating point for a digital receiver.

# Simulated APD Curves for OFDM and Impulse Radios in 50MHz bandwidth




10MHz PRF impulse radio has nearly identical APD to 1/3 duty cycle OFDM in region of interest.

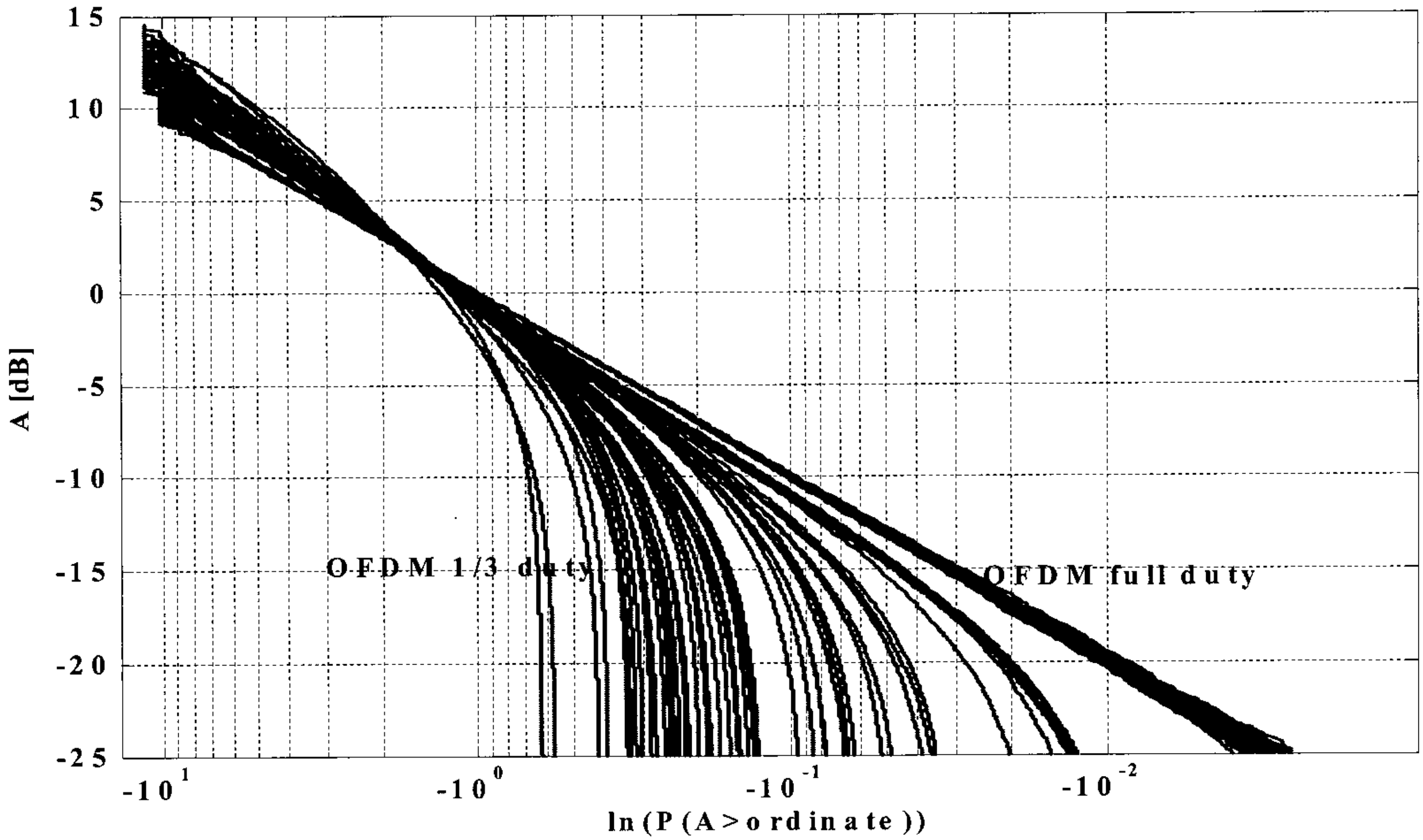
3MHz and 1MHz PRF radios have significantly higher SIR ratios corresponding to the 1.8% P(A>ord.) line than the 3-band OFDM system.

All these impulse radios would be permitted under current part 15f legislation.

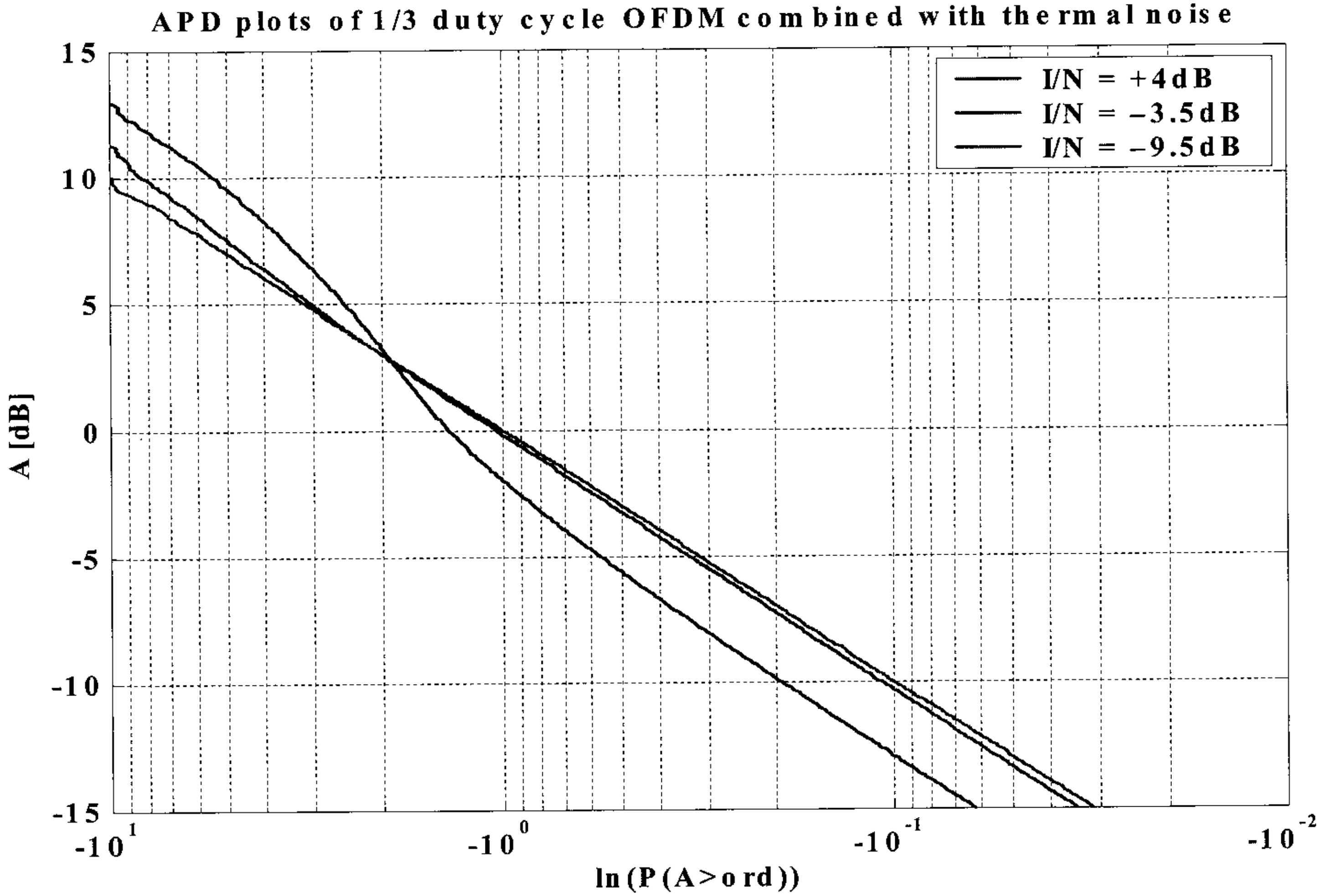
# Consideration of one dominant UWB interferer is worst case analysis

- The above analysis assumes that the dominant source of noise/interference is a single instance of the considered waveform
- For this to be true:
  - A single interferer must be very close to the victim receiver
    - Path loss of ~63dB, corresponds 8.8m @ 4GHz in free space
  - The link margin of that receiver must allow room for the interferer overwhelm the thermal noise floor of the victim receiver
- This will not be true if:
  - The additive combination of several uncoordinated UWB interferers combines to approximate a Guassian APD (due to the CLT).

# Summation of 5 MB-OFDM Signals with randomly chosen delays (50 trials)



# APD plots of 1/3 duty cycle OFDM combined with thermal receiver noise



# Conclusions

- Using the NTIA APD methodology for the worst-case scenario of a single dominant interferer shows:
  - That the required SIRs for impulse radios with PRFs in the 1-10MHz range are all greater than the SIR needed for the 3-band OFDM waveform, assuming a 50MHz victim receiver bandwidth. This applies in the probability range from 1.8% to 13%, which is considered most important.
  - Similar conclusions apply to lower victim receiver bandwidths after applying a proportional scaling to the impulse radio PRFs.
- Interference caused by a population of MB-OFDM devices will have a more benign aggregate APD.
- Receiver thermal noise and other external interference sources will have a mitigating effect on the APD of an interfering MB-OFDM signal

# BACKUP SLIDES

# Appendix 1: Simulation Methodology

- Short MATLAB scripts were used to create all the plots
- The OFDM signal was created by concatenating 200 inverse FFTs, where the inputs to each IFFT were complex QPSK random sequences of length 128.
- To simulate 1/3 duty cycle, an all-zeros vector of length (37+165+165) was added after each IFFT result.
- The resultant signal was normalized to unit power
- For each considered amplitude the fraction of samples in the whole sequence exceeding the level A was recorded

# Simulation Methodology for Impulse Radio

- Random BPSK sequences of length 100 were upsampled by a factor of Fs/PRF by zero insertion
- A Root Raised Cosine filter of bandwidth 50MHz was use applied to the upsampled bi-polar signal
- After scaling the signal to unit power, the fraction of samples in the whole sequence exceeding the level A was recorded and plotted

# Appendix 2: Analytic Expression for APD (I.e. 1-CDF) of OFDM waveforms

For measurement bandwidths that exceed 10 subcarriers the OFDM waveform has an approximately Gaussiam pdf for the real and imaginary parts.

Hence the envelope, $r$, is approximately Rayleigh distributed and

$$PDF(r) = \frac{r}{\sigma^2}\exp(-r^2/2\sigma^2), \quad r \geq 0$$

$$CDF(r) = \int_0^r \frac{u}{\sigma^2}\exp(-u^2/2\sigma^2)\, du$$

$$= 1 - \exp(-r^2/2\sigma^2), \quad r \geq 0$$

# Analytic Expression for APD (I.e. 1-CDF) of OFDM waveforms

Hence, $1 - CDF = \exp(-r^2/2\sigma^2)$

For unit power, $2\sigma^2 = 1$, and

$APD = 1 - CDF \quad = \exp(-r^2)$

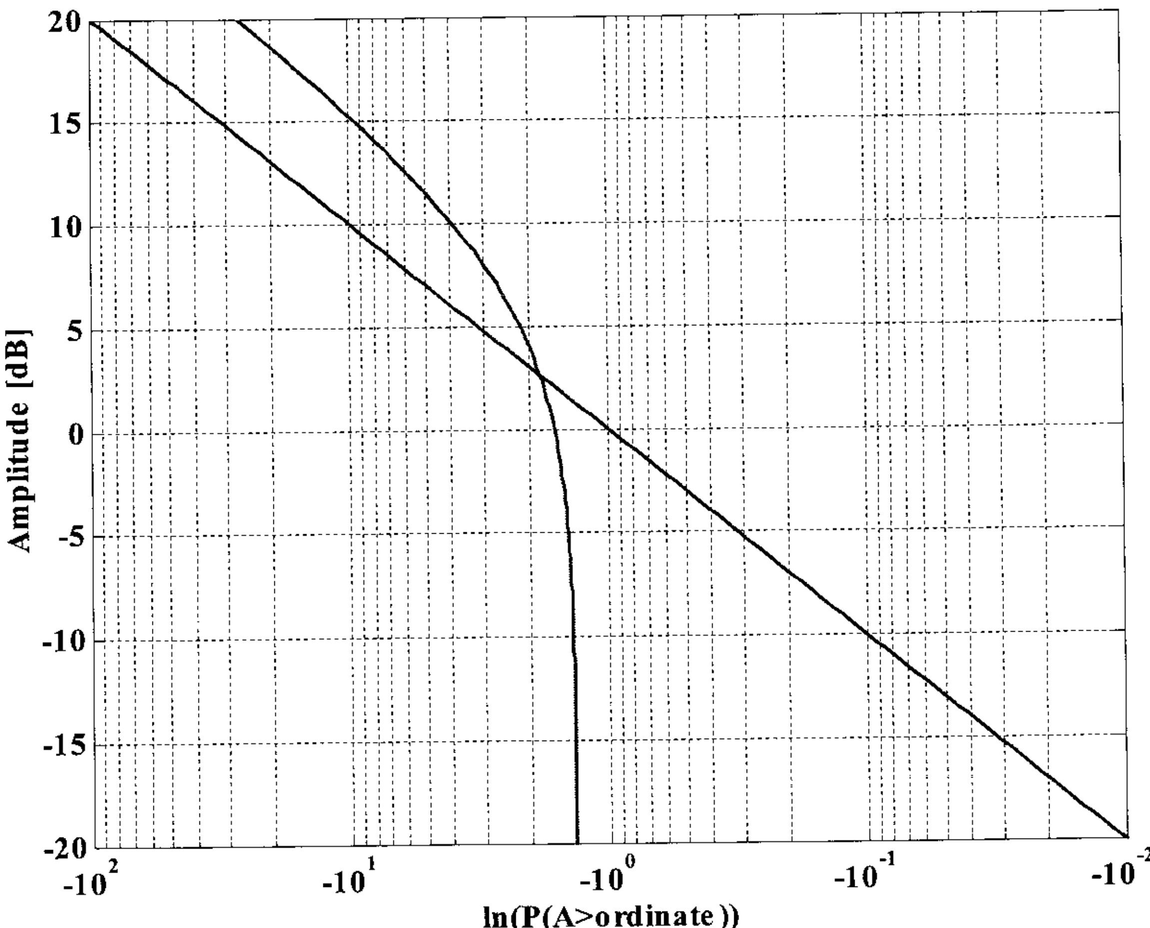
(Since $r^2 = 10^{A_{dB}/10}$, then $\log_{10}(-\ln(1 - CDF)) = A_{dB}/10$)

If we introduce a duty cycle factor of $d$, $2\sigma^2 = d$, so:

$$CDF = \frac{d-1}{d} + \frac{1}{d}\left[1 - \exp(-r^2/d)\right],$$

$$APD = 1 - CDF = \frac{1}{d}\exp(-r^2/d)$$

# Analytically derived APD plot for MB-OFDM




```
% APD plots
d = 3*165/128; % duty cycle ratio
x=linspace(-20,20);
rsq=10.^(x/10);
apd3=-rsq/d - log(d);
apd=-rsq;
semilogx(apd,x,apd3,x)
xlabel('ln(P(A>ordinate))')
ylabel('Amplitude [dB]')
grid
```